Research and Analysis of the Causes of Train Derailment Accidents Based on ISM Explanatory Structure Model

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Abstract: Train derailment happens from time to time,every accident will cause great economic losses and serious casualties. The reasons of train derailment are complicated,which makes it difficult for relevant technicians to take effective preventive measures. This paper studies the direct and indirect causes of train derailment by using interpretive structural model and transforms them into multi-level hierarchical directed graphs. The important factors affecting train derailment accidents are found out,and countermeasures for effective prevention of train derailment accidents are put forward. It will provide references for researchers in the field of train derailment studies and promote the rapid development of railway in our country.

Keywords: Systems Engineering; Interpretive Structural Model; The Train Derailed; Cause Analysis

1. Introduction

The operation and control of trains are related to the safety of passengers' life and property. With the large-scale popularization of rail transit,railway transportation has become the first choice for many people to travel,but railway traffic accidents often occur,especially the train derailment problem has become one of the important factors affecting the long-term stability of the rail transit industry. There are many reasons affecting the occurrence of train derailment accidents,and the direct and indirect relationship between each reason can not be inferred subjectively,but must sort out its hierarchy,so as to put forward targeted solutions.

Using ISM(Interpretative Structural Modeling Method) in system engineering to explain structural models,analyze the influencing factors of train derailment accidents,establish multi-level hierarchical directed graphs,and obtain the root causes affecting train derailment accidents. At the same time,master the general direction of solving the train derailment accident,in order to get effective countermeasures to prevent the train derailment accident.

2. Basic principles and calculation procedures of ISM

ISM interpretive structure model is based on the correlation matrix principle in graph theory,which is used to analyze methods with many complex factors and explore the direct and indirect relationships between each factor in the system. Through the transformation between matrix and graph,the structure system of complex factors is obtained,which can clearly express the relationship of each factor in the system,so as to grasp the root cause of the influence of the system. The ISM interprets structural models as follows:

Step-1:Find the elements according to the specific problem and build the set S .

Step-2:The relationship between elements is analyzed and the adjacency matrix A is constructed.

Step-3:According to the Boolean logic operation,add the adjacency matrix A and the identity matrix I to get matrix $V = A + I$,and then perform matrix $V = A + I$ as A matrix power operation according to formula (1) to get the reachable matrix $(A+I)^r$,in which the direct and indirect relations between various elements can be seen.

$$A + I \neq (A+I)^2 \neq (A+I)^3 \neq \cdots \neq (A+I)^r = (A+I)^{r+1} \quad (1)$$

Step-4: Determine the level of each element,and determine the set of each element to reach all elements as reachable set $T_{(S_i)}$; Determines that the set of all elements that can reach an element is the antecedent set $Y_{(S_i)}$. Then a new set O_1 is found according to formula (2).

$$T_{(S_i)} \cap Y_{(Si)} = T_{(Si)} \quad (2)$$

The elements are divided into the first level of the digraph O_1 . At the same time,the reachable matrix $V = (A+I)^r$ strips out the rows and columns of the elements concerned,giving V' . Then,according to the above calculation method,a new set of elements is obtained,which are divided into the second level of the digraph O_2 ,and the set O_3 , O_4 , O_5 , O_6 ,... ,and the elements are graded.

Step-5: Draw a multi-level hierarchical digraph,using directed line segments to connect elements in different levels and express the relationship between elements.

3. Application process of ISM in train derailment accident research

3.1 Summary of main factors affecting train derailment

Through the review of relevant literature[2]-[5] in this field and the reflection of train derailment accidents at home and abroad,combined with the railway operation situation,it is summarized from four categories: natural disaster,the status of relevant personnel,the status of relevant equipment and relevant management measures the 20 relevant factors are shown in Table 1.

Table 1 Summary of relevant factors.

Element category	Specific elements under this category
Natural disaster	Earthquakes(S_1),Mudslides(S_2),Collapses(S_3)
Relevant person status	Mental state(S_4), Professionalism(S_5), Driving state(S_6), Mental quality(S_7)
Related facility status	Service life(S_8),Train operating parameter(S_9),Rail health status(S_{10}), Communication network state(S_{11}),Electric driving capacity(S_{12}),Wheelset wear degree(S_{13}),Train dynamics parameter(S_{14}),Train loading degree(S_{15})
Relevant management measures	The strength of the implementation of rules and regulations(S_{16}), The judgment of train operating conditions(S_{17}), The analysis of relevant data(S_{18}), The cleaning and maintenance of the track(S_{19}), The signal management and Control of the railway(S_{20})

3.2 Construct the adjacency matrix of the problem

After comprehensive analysis of all factors, the direct influence relationship between each two factors is obtained. Meanwhile, in the process of constructing the matrix, 1 is used to indicate that the two have a direct influence relationship, and 0 is used to indicate that the two have no direct influence relationship, as shown in Table 2.

Table 2 the adjacency matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}
S_1	0	1	1	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
S_2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S_3	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S_4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_5	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1
S_6	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	0
S_7	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_8	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0
S_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
S_{10}	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	1	1
S_{11}	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1
S_{12}	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	1	0	1	1
S_{13}	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0
S_{14}	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0
S_{15}	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
S_{16}	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0

S_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{18}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S_{19}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
S_{20}	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0

3.3 Construct the reachability matrix of the problem

The adjacency matrix and the identity matrix above are added and iterated according to formula (1). The reachable matrix is obtained after five iterations, as shown in Table 3.

Table 3 the reachable matrix.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}
S_1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
S_2	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
S_3	0	0	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
S_4	0	0	0	1	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_5	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
S_6	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_7	0	0	0	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
S_8	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_9	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{10}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{11}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{12}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{13}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{14}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{15}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1
S_{16}	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S_{18}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
S_{19}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1
S_{20}	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1

3.4 Hierarchical division

According to the generated reachable matrix, the reachable set and the leading set are sorted out, and then the intersection of the reachable set and the leading set is obtained as a whole, and the hierarchical division is discussed according to formula (2). According to the calculation, it is divided into 7 layers, from top to bottom, which are the first level, the second level and the third level...... The explanatory structure model diagram is shown in Figure 1. In order to make the graph expression more clear, the strong association relationship, reflexive relationship and leap-over relationship are not considered.

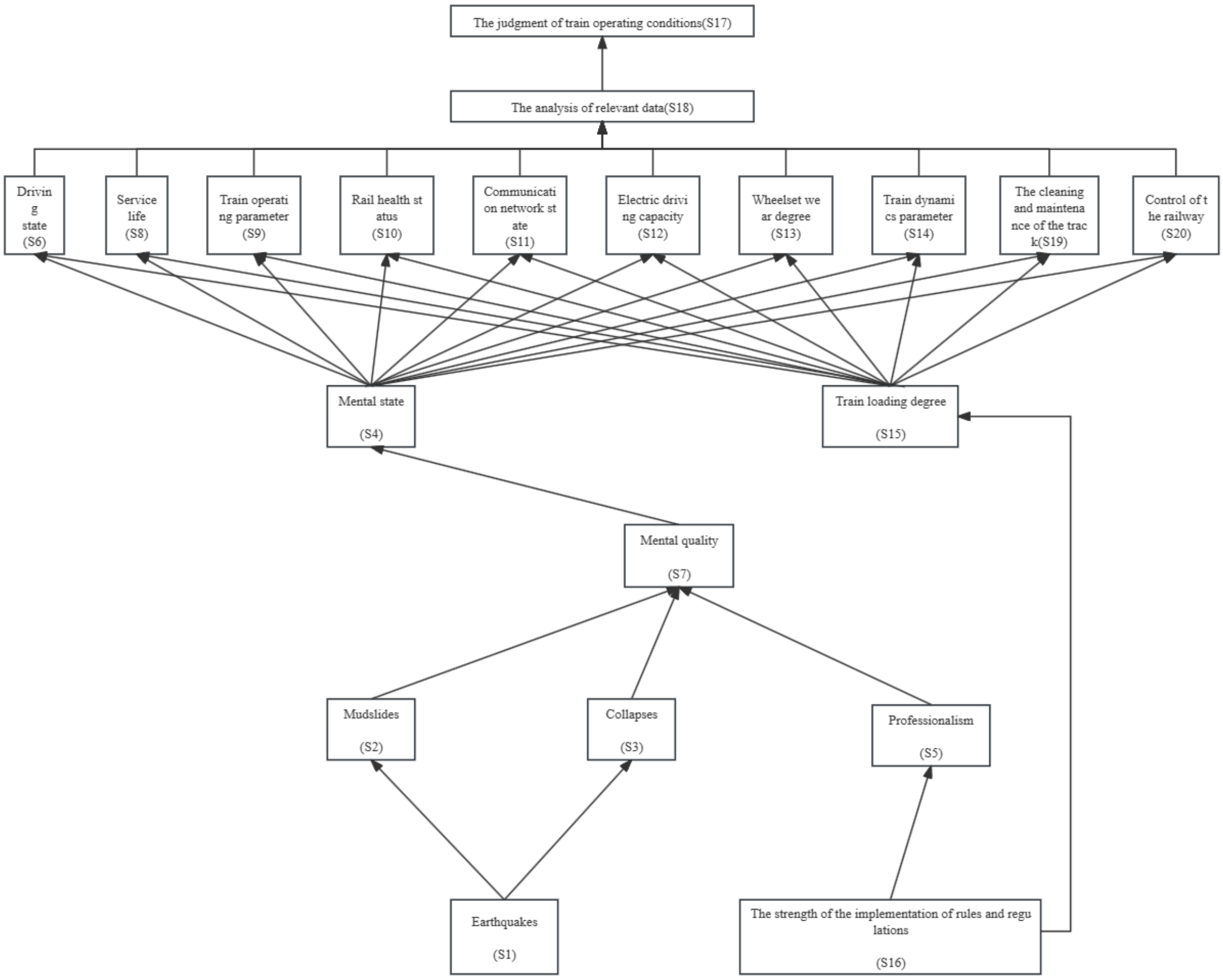

Figure 1 Structural model of train derailment accident cause explanation

4. According to model analysis

According to the first-level analysis, it is clear that The judgment of train operating conditions (S_{17}) has a relatively obvious impact on the occurrence of train derailment accidents. If the relevant staff cannot accurately predict whether the train can run from the train itself, the condition of the line, weather conditions and other conditions through their professional ability, the probability of train derailment will be increased.

The factors at the second level are all influenced by the factors at the third level.The third level of factors are Driving state(S_6), Service life(S_8), Train operating parameter(S_9), Rail health status(S_{10}), Communication network state(S_{11}), Electric driving capacity(S_{12}), Wheelset wear degree(S_{13}), Train dynamics parameter(S_{14}), The cleaning and maintenance of the track(S_{19}), The signal management and control Control of the railway(S_{20}), these factors are related to the equipment related to the train derailment event, including the equipment on the train, the track, and the rail transit system related equipment, combined with the first layer of factors, need to make further analysis from the data feedback information of these devices, so as to achieve the control of the train derailment accident.

Factors at The fourth level include Mental state(S_4) and Train loading degree(S_{15}), where Train loading degree is directly affected by The strength of the implementation of rules and regulations (S_{16}). The fifth level of Mental quality(S_7)directly affects Mental state(S_4).

From the relationship between the fifth and sixth layers, Mudslides(S_2), Collapses(S_3)and Professionalism(S_5)will affect Mental quality(S_7), and then lead to operational errors resulting in irreversible losses caused by train derailment. From the relationship between the sixth and seventh layers, Mudslides(S_2)and Collapses(S_3)are probably secondary disasters of Earthquakes(S_1), while Mental quality(S_7)is affected by The strength of the implementation of rules and regulations(S_{16}). Only by doing emergency drills for earthquakes and other disasters and formulating emergency measures can we reduce the loss caused by accidents as much as possible. At present, the railway related system is relatively complete, but the implementation needs to be improved. We can start from the aspect of improving the professional quality of employees to improve the business ability of railway staff.

5. Conclusion

This paper analyzes the occurrence of train derailment accidents through the interpretation structure model, and uses the means of hierarchical division to sort out the relationship between various factors, and finds that the deep cause is the seventh layer factor -- earthquake and the implementation of rules and regulations, which represent the emergency factor and the human factor respectively. Combining with the relationship between other levels, the protection direction of train derailment accident is put forward, which is conducive to the "long-term stability" of railway transportation.

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